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Dr. David Sogin, Director of Graduate Studies

THE ROLE OF LARYNGEAL FUNCTION IN BREATHING FOR SINGING

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Musical Arts in the
College of Fine Arts at the University of Kentucky

By
Ellen Graham

Lexington, Kentucky

Director: Cynthia Lawrence, Professor, Endowed Chair in Music (Voice), Chair of the
Vocal Area

Lexington, Kentucky 2014

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ABSTRACT OF PROJECT

THE ROLE OF LARYNGEAL FUNCTION IN BREATHING FOR SINGING

Poor breath management is problematic for singing. Voice students and singing teachers typically attribute breath management issues to abdominal-diaphragmatic breathing technique. The present study seeks to determine whether glottal insufficiency may also contribute to singer's breath management problems. Studies have revealed a relationship between incomplete vocal fold closure and inefficiency in the speaking voice. However, the effect of incomplete vocal fold closure on vocal efficiency in singers has yet to be determined. Since the larynx cannot be observed without the assistance of clinical instrumentation, not readily available in the voice studio, issues at the glottal level may be underappreciated as a contributor to poor breath management in the singer.

Two groups of voice students identified with and without breath management problems underwent aerodynamic and acoustic voice assessment as well as videostroboscopy of the vocal folds to quantify the prevalence of incomplete vocal fold closure. These assessments revealed four groups: (1) those with glottic insufficiency and no perceived breathiness; (2) those with glottic sufficiency and perceived breathiness; (3) those with glottic insufficiency and perceived breathiness; and, (4) those with glottic sufficiency and no perceived breathiness. Results suggest that previously undiscovered glottal insufficiency is common, though the correlation with identified breath management problems was not statistically significant. Acoustic and aerodynamic measures including noise-to-harmonics ratio, maximum phonation time, airflow rate, subglottal pressure and laryngeal airway resistance were most sensitive to glottic insufficiency.

KEYWORDS: glottic insufficiency, breathiness, singing voice, stroboscopy, professional voice

MULTIMEDIA ELEMENTS USED: JPEG (.jpeg)

Ellen Graham
January 31, 2014

THE ROLE OF LARYNGEAL FUNCTION IN BREATHING FOR SINGING

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C H A P T E R 1 : INTRODUCTION

Background

The physiologic vocal mechanism consists of three subsystems: respiration, phonation and resonance. The balanced interaction of these subsystems is important for normal voice production. However when one of these subsystems is not functioning properly and efficiently, the other two subsystems will adjust to compensate causing a significant impact on voice production.¹ The vocal folds vibrate when there are sufficient air pressures below, between and above the vocal folds, resulting from a constant flow of air through the vocal folds provided by the respiratory system. The phonation produced by the vibrating vocal folds is then dampened and enhanced in the vocal tract, producing a distinctive voice quality.

Singers study for years to achieve this optimal, yet somewhat elusive balance of voice production elements. Breathiness in the voice, or inefficient management of breath, can be particularly problematic for the singing voice. Vocal pedagogue, Barbara Doscher suggested that breathiness in the voice is more commonly caused by poor breathing and/or inefficient resonance.² As a result, voice teachers may interpret a student's inability to sing a long phrase on one breath as a problem arising from the student's breath support. Doscher defines breath support as the antagonistic interaction of the abdominal and thoracic muscles, resulting in a steady stream of air.² Another term commonly used to describe this kind of abdominal-thoracic breath support is the Italian term *appoggio* (from the word *appoggiare*, which means "to lean"). James McKinney made a further distinction between breath support and the term breath control. He defines

breath control as the dynamic relationship between the breath and the vocal folds which determines how long an individual can sing on one breath.³

To put McKinney's definition of breath control into scientific terms, the vocal folds provide the vibrating source for phonation, but also function as a variable valve to modulate airflow as it passes through vibrating vocal folds during phonation. Phonation relies on pulmonary-respiratory power, supported by the abdominal and thoracic musculature, however vocal fold closure also contributes to the efficient use of air.¹ For the purpose of this study the phrase "breath management" will be used to encompass the interactive relationship of vocal fold (glottic) valving and pulmonary respiration.

From the perspective of a speech-language pathologist, inefficient use of air in voice production may be attributed to issues at the level of the vocal folds, as well as issues of breath support as classically defined by vocal pedagogues. Issues at the laryngeal level can be confirmed by performing an assessment of vocal fold vibratory parameters with laryngeal videostroboscopy. Stroboscopy provides a specialized laryngeal exam that permits a speech-language pathologist or otolaryngologist to assess specific vocal fold vibratory parameters in addition to assessing the gross structure and function of the larynx. One of these parameters is vocal fold closure during phonation, also known as glottic closure. The term glottis refers to the space between the vocal folds. Glottic closure is an important indicator of efficient vocal fold valving during phonation making it an important factor during speaking and singing voice production.⁴

Research has demonstrated that glottal configuration plays an important role in the production of the supported singing voice.⁵ In a study on the role of the vocal

function exercises as part of the practice regimen for singers, Sabol, et al. demonstrated that improving glottal closure increased vocal efficiency for singing.⁶ Schneider, et al. demonstrated a positive correlation between incomplete glottic closure and vocal inefficiency in normal voiced female speakers.⁴ At present, there have been no studies that examine the correlation between glottic closure and perceived breath management problems in singers.

Statement of Problem

Breathiness in the singing voice is a vocal technique issue that a voice teacher can easily identify and address, but the cause of the breathiness may be more difficult to identify. An issue that is perceived by voice students and voice teachers as being related to breath support may potentially be the result of air loss due to incomplete closure of the vocal folds during voice production. Since the larynx cannot easily be observed without the assistance of clinical instrumentation, issues at the glottal level may not be recognized as contributing to technical issues in the singing studio. This could potentially lead to frustration on the part of the student and the teacher. In addition, insufficient glottal closure may also lead to other vocal issues as the singer attempts to compensate for the loss of air. *Therefore, the purpose of this study is to examine the correlation between the perception of breathiness in singing and actual glottal configuration in singers.*

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C H A P T E R 2 : REVIEW OF LITERATURE

This chapter will review literature pertinent to glottal configuration, breath support for singing, evaluation of voice, laryngeal muscle activity and abnormal laryngeal findings in asymptomatic voices. The statement of purpose and hypothesis for this study will follow. The chapter concludes with a discussion of the significance of the current study. First, a brief overview of laryngeal anatomy as it relates to breath support and a description of clinical voice assessment tools will be provided.

Relevant Anatomy and Physiology of the Larynx

A basic understanding of laryngeal muscle anatomy is helpful in understanding laryngeal function in singing. The larynx consists of nine cartilages and one bone, and includes ligaments, membranes, and intrinsic and extrinsic muscles. The thirteen intrinsic muscles have their origin and insertion on the cricoid, arytenoid or thyroid cartilages.¹

The vocal folds are comprised of muscle, ligament and membranous layers. The thyroarytenoid (TA) muscle, which makes up the bulk of the vocal fold, originates from the thyroid cartilage anteriorly (front) and inserts on the vocal processes of the arytenoid cartilages posteriorly (back). The TA, along with the lateral cricoarytenoid (LCA) and interarytenoid (IA) muscles, function to adduct the vocal folds and close the glottis during phonation.^{1,7}

Assessment Measures

Clinical voice assessment methods have traditionally been classified into five domains: auditory-perceptual measures, acoustic analysis, aerodynamic analysis, visual imaging of the vocal folds and patient self-assessment.

Perceptual Measures

Auditory-perceptual assessment involves the clinician's perception of the patient's voice. The Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) was developed to provide a protocol for clinicians to rate adults with voice disorders. A 100 mm visual-analog scale is used to rate the overall severity, roughness, breathiness, strain, pitch and loudness of a voice. Two separate studies have established the validity and reliability of the CAPE-V as a tool for assessing the quality of a subject's speaking voice.^{8,9}

Measures of self-assessment ask patients to provide a description of their perception of the voice problem including social, functional and physical domains. For the present study, the Singing Voice Handicap Index (SVHI) was used. The SVHI is a widely accepted, self-administered questionnaire that rates statements about quality of voice on a scale of 0-4. It was created and validated for use specifically in patients with singing voice problems.¹⁰

Acoustic Measures

Acoustic analysis of voice is achieved by measuring the voice signal using a microphone to electronically convert voice into an electronic signal, which is then analyzed.¹¹ Measures such as frequency, intensity and noise-to-harmonics ratio are calculated with this equipment. Acoustic measures are taken from a sustained pitch on an engaged voice, produced without vibrato. Definitions of the measures taken for this study are as follows:

- *Fundamental frequency (F_0)*: Acoustic correlate of pitch. F_0 represents the number of vibrations of the vocal folds per second. It is measured in Hertz (Hz).¹² The normal range of fundamental frequency in the speaking voice is 100 to 150 Hz for males and 180 to 250Hz for females.
- *Jitter*: Measure of pitch perturbation. It is the cycle-to-cycle variation in frequency. It may be measured in percentage (%) of mean cycle-to-cycle perturbation in frequency to the mean overall frequency of the voice signal.^{12,13} Normative data for jitter is less than 1.00%.¹⁴
- *Shimmer*: Unit of measurement of the small cycle-to-cycle changes of the amplitude of the vocal fold signal. It is measured in decibels (dB).¹³ Normative data for shimmer is less than .35 dB.
- *Noise-to-harmonics ratio (NHR)*: Measure of the acoustic noise energy in the voice signal. NHR is considered normal when it is less than .19.^{1,13} A high level of noise is indicative of aperiodic vocal fold vibration and breathiness.
- *Maximum phonation time (MPT)*: Maximum duration that a vowel can be sustained while using maximum airflow volume.¹ This measure varies with age, sex, size and health.¹²

Aerodynamic Measures

Aerodynamic analysis informs vocal function by measuring airflow, air pressure and lung volumes. The aerodynamic measures obtained for this study and defined below were vital capacity, mean airflow rate, mean peak air pressure, laryngeal airway

resistance and phonation threshold pressure. These measures are obtained from a sustained pitch on an engaged voice, produced without vibrato.

- *Vital capacity*: Maximum amount of air a person can expel from their lungs after a maximum inhalation, measured in liters.¹ This measure varies with age, sex, size and health.
- *Mean airflow rate*: Also called mean airflow during voicing, is the total volume of air used during phonation for the duration of phonation. It is defined in liters per second (L/sec).⁷ Normal measures for mean airflow rate are 80-200 ml/sec.
- *Subglottal pressure (P_{sub})*: Measurement of air pressure beneath the vocal folds necessary to overcome the resistance of the approximated folds to initiate and maintain phonation.¹ Normal measures for subglottal pressure (P_{sub}) are 5-8 cm H₂O.¹³
- *Laryngeal airway resistance (LAR)*: Ratio of subglottal pressure to mean airflow rate; a valuable measure of glottal efficiency.⁷ In normal voices LAR is 30-45 cm H₂O (L/sec.)¹³
- *Phonation threshold pressure (PTP)*: Minimum subglottal pressure needed to initiate vocal fold vibration, measured at the quietest possible initiation of voicing. Normal measures for phonation threshold pressure are 3-5 cm H₂O.⁷

Visual Assessment

Visual-perceptual assessment of the vocal folds may be accomplished in a variety of ways including indirect assessment using a laryngeal mirror, flexible or rigid

endoscopy to identify pathology, videostroboscopy and high-speed video imaging to assess vocal fold vibration patterns. With the latter procedures, the symmetry and periodicity of vocal fold movement, glottal closure patterns and mucosal wave may be studied.^{9,15} For this study, glottal configuration and how it subsequently affected objective measures were examined specifically. Below are examples of different glottal configurations. (Figures 2.1, 2.2, 2.3, 2.4)

Glottal Configuration

Research has shown glottal configuration to contribute to vocal function, vocal efficiency and tone quality. The present study is concerned with glottal configuration as it relates to perceived breathiness and the impact of glottal closure on vocal efficiency. The following studies examined glottic insufficiency in normal voiced females, vocal function in trained and untrained singers and glottic configuration for different voice qualities. Each determined that better glottic closure contributed to better vocal efficiency.

Schneider, et al. conducted a study on normal-voiced young women to determine the effect of glottic closure configuration on singing and speaking characteristics.⁴ In all, 520 young, normal-speaking women were examined by videostroboscopy for four different phonation conditions: soft, loud, low, high. Subjects were further divided into four groups based on level of glottic closure. Subjects with the most complete closure reached the highest sound-pressure levels, while subjects with persistent insufficiencies had a limited capacity to increase the intensity of the singing and speaking voice. The results support the relationship of insufficient glottal closure and reduced vocal capabilities. However, the only measures used in evaluating vocal efficiency were acoustic measures: fundamental frequency, intensity and sound pressure level.

Additionally, since only female subjects were examined the results do not necessarily reflect glottal closure or vocal efficiency in men.

Sabol, et al. examined the efficacy of the vocal function exercises (VFE) in the practice regimen of singers.⁶ The study investigated the effects of isometric-isotonic vocal function exercises, practiced regularly for 4 weeks, on parameters of voice production in the healthy singer. The population size in this study was small (20 subjects), but did include both male and female graduate-level trained singers. Subjects were divided into a control group and an experimental group. Subjects in the experimental group demonstrated significant improvements in posttest aerodynamic measures of flow rate, phonation volume, and maximum phonation times, suggesting an increase in glottal efficiency. The present study also examines both male and female singers with college-level training.

A more recent examination by Tay, et al. on the effects of VFE also showed that specific acoustic and aerodynamic measures improved in subjects who routinely used the exercise regimen.¹⁶ This study conducted on a group of 22 aging community choral singers showed significant improvements in perceived roughness, maximum phonation time, jitter, shimmer, and noise-to-harmonics ratio after VFE training, suggesting better glottal airflow. Maximum phonation time, jitter, shimmer and noise-to-harmonics ratio were parameters examined in the present study and were shown to be affected by glottal configuration.

The configuration of the glottis during voice production has also been shown to affect the quality of the tone produced. A study by Murry, et al. examined glottal

configuration associated with fundamental frequency and vocal registers to determine if glottal configuration changes from modal to falsetto voice.¹⁷ This blind study examined 8 normal-voiced, non-singers (4 male and 4 female), ranging in ages from 26 to 48. Simultaneous measurements of mean airflow rate, fundamental frequency and vocal intensity were made during flexible video endoscopic recording of the vowel /i/ sustained in modal and falsetto vocal registers. The results of the study showed incomplete closure in higher registers for all subjects and that register change affected the degree of closure, not shape. The study established that mean airflow rate may be regarded as a criterion for judging glottal closure. The results of the present study also support the use of mean airflow rate to judge glottal closure.

A study by Herbst, et al. demonstrated that different glottal configurations produce different tone qualities.¹⁸ The study examined four qualities of singing voice in one classically trained baritone. The researchers named the four qualities "naive falsetto," "countertenor falsetto," "lyrical chest" and "full chest." Laryngeal configuration and vocal fold behavior in these qualities were studied using laryngeal videostroboscopy, videokymography, electroglottography, and sound spectrography. The four voice qualities were found to be produced by independently manipulating mainly two laryngeal parameters: (1) the adduction of the arytenoid cartilages and (2) the thickening of the vocal folds. While the parameters of this study by Herbst, et al. are significantly different than the present study, it is interesting to note the different glottal configurations for different registers of the voice when assessing glottic closure.

The Supported Singing Voice

Classically trained singers are a subset of professional voice users with unique vocal demands and pathologies. Several important studies have specifically examined the perception of breathiness and breath support. Separate studies conducted by Griffin, et al., Watson, et al. and Sonninen, et al. examined the perception of breath support as it compared to actual physiological characteristics.^{5,19,20} The design of each study varied slightly, though two studies specifically used surveys in which the subjects were asked to describe their concept of breath support. Each of these studies used singers with extensive training in classical singing, though none had enough subjects to establish statistical validity.

Griffin, et al. conducted a study examining the characteristics of the supported singing voice as evidenced by acoustic, aerodynamic and stroboscopic measures, as compared to supported singing as perceived by singers.⁵ The results of this study indicated that changes in glottal configuration, such as closing the glottis more tightly, do play an important role in the production of the supported singing voice.

The study looked at eight classically trained singers, with a minimum of 5 years of private voice study. Subjects were asked to describe the characteristics of a supported singing voice and how they produce a supported singing voice. Measurements taken were acoustic, airflow, electroglottography, and stroboscopy. Stroboscopic recordings were made with a flexible endoscope and were evaluated for glottal configuration, glottal open quotient, amplitude of vocal fold vibration and laryngeal configuration. All measurements were made on samples of the supported and unsupported singing voice at low, medium and high pitches.

It may be interesting to note that the results of the voice measures did not support the singers' perceptions of how they manage breath. This can present a challenge when comparing perception to the results of clinical measures. The results of the airflow measures were useful in determining elements of breath management and did suggest gender-related differences in support. Tighter glottic closure was clearly visible in female subjects during supported singing. On the other hand, airflow measures suggest that respiratory activity may play a more important role in males in supported voice in their upper range.⁵

A study by Watson and Hixon examined support for singing, particularly the activity of the ribcage, diaphragm and abdominal muscles, and the singers' perception of how they breath for singing.¹⁹ Like Griffin's study, the study population was small, consisting of six male subjects, all operatically trained baritones. The subjects were each asked to describe how they believed they inspired and expired during singing. They then were recorded performing three predetermined pieces of music. The results of the study quantified the mechanical function of the ribcage, diaphragm and abdomen during respiration for singing. The researchers also observed that the subjects' descriptions of how they thought they breathed bore little resemblance to how they actually breathed for singing, again demonstrating the challenge of comparing perception to clinical measures.

Sonninen, et al. also attempted to provide perceptual, acoustic and physiological correlates of support in singing.²⁰ This study consisted of seven classically trained singers who performed a series of tasks, which were recorded for review by a panel of outside assessors. The subjects were recorded singing the syllable /pa/ at two set pitches and also an arpeggio spanning the range of an octave and a half. Acoustic signals were recorded to

a tape recorder and electrographic signals were obtained by a dual-channel electroglottograph. Intraoral pressure was also measured to provide an estimate of subglottic pressure. Three groups of listeners evaluated the audio samples, which had been randomized.

The purpose of the study by Sonninen, et al. was to determine if it is possible to differentiate between supported and unsupported voice samples based on impression. Additionally, their results suggest that best voice quality (supported voice) is characterized by intermediate subglottal pressure and electroglottograph slope values, thus, neither pressed nor breathy. The results also showed a difference between male and female measures.

The following studies are indirectly related to the present study, though each presented a component that is relevant. Several studies described below used similar methodologies to the present study or dealt specifically with professional voice users such as actors, and singing teachers. One study looked at gender differences in laryngeal structure and function and another examined glottal insufficiency, but in a different context. While not directly related to the present study, these studies illustrate the importance of understanding what is happening at the laryngeal level when evaluating a student's technical issues.

A study conducted by Lundy, et al. using similar methodology to that of the present study examined the incidence of abnormalities in the mucosal lining of asymptomatic voice students.²¹ The results of the study showed that a surprisingly high number of otherwise asymptomatic singing students demonstrated abnormal laryngeal

findings. An additional study by Sataloff, et al. showed abnormal laryngeal findings in otherwise healthy singing teachers.²² Seventy-two trained singers without significant voice complaints were examined using videostroboscopy. Of those 72, abnormalities were found in 86.1%. Abnormalities included surface pathologies, laryngopharyngeal reflux and incomplete glottic closure.

A study by Lerner, et al. conducted on a group of acting students acknowledged the special vocal demands of actors and examined voice disorders particular to this particular subset of professional voice users.²³ The methodology of this particular study is similar to that used in the present study, as is the number and distinctiveness of the study population. This retrospective study examined the data of first-year acting students at the Yale School of Drama. Subjects filled out a VHI-10; acoustic measures taken were maximum phonation time, jitter and shimmer; and, videostroboscopy was assessed for presence of reflux and hyperfunction. This study attempted to systematically analyze the prevalence of vocal pathologies among actors, particularly laryngeal hyperfunction, decreased mucosal wave and incomplete glottal closure. Lerner, et al. identified a high percentage of both incomplete glottal closure and hyperfunction.

A study conducted by Sulter and Wit on glottal volume velocity waveform also observed gender differences on certain aerodynamic measures.²⁴ Glottal volume velocity waveform characteristics of 224 subjects, divided into 4 groups based on gender and vocal training, were determined. In addition, their relation to sound-pressure level, fundamental frequency, intra-oral pressure and age were analyzed. Several statistically significant differences were found between men and women, including minimum flow, ac flow, average flow, maximum flow declination rate, closing quotient, glottal resistance

and closed quotient. These differences, in light of a previous study conducted by Sulter, were attributed to physiologic differences between the male and female larynx.^{24,25}

Ingo Titze's study on the physiologic and acoustic differences in the male and female voice established several significant differences between the male and female larynx.²⁶ Comparisons of the overall size of the larynx, vocal fold membranous length, elastic properties of tissues and pre-phonatory glottal shape were made by using computer simulated vocal fold contact areas. Male vocal folds were shown to be 20% longer, have wider amplitude of vibration and a bulge on the medial surface during phonation. Female vocal folds, which are shorter, have a more linear convergence and the vocalis muscle is generally in a lesser state of contraction. Mean airflow rate was also shown to relate to overall size of the larynx (lower for males; higher for females).

There have been several studies on muscle tension dysphonia, including one by Belfasky, et al. that showed that muscle tension dysphonia is common in people with underlying glottal insufficiency.²⁷ In this study 84% of male subjects and 60% of female had evidence of vocal fold bowing. Of the 72 with bowing, 94% had abnormal muscle tension patterns. Persons with vocal bowing were 17 times more likely to exhibit abnormal muscle tension patterns. Similar studies looking at muscle tension dysphonia have also shown a connection to underlying factors at the laryngeal level, and poor breath support.^{28,29}

Purpose of the Study

The purpose of this study was to determine if there is a link between perceived breathiness as observed by teacher and student in the voice studio, and glottal

insufficiency as shown by visual imaging and other acoustic and aerodynamic tests performed in a clinical setup. In the current study, we tested the hypothesis that singers who are reported as having breath management problems often have a glottal configuration issue. The overall goal of this study was to quantify this observation, thereby increasing awareness of glottal configuration issues among voice teachers, voice students, and speech-language pathologists.

Hypotheses

The objective of this study was to test the hypothesis that some singers who report or are reported to have breathiness during singing have glottic insufficiency issues as identified by visual examination of the vocal folds. Two specific aims for the study were established.

Specific Aim 1: To determine the relationship between perceived breathiness during singing and glottal configuration, (i.e. gapping, incomplete closure). Singers underwent visual imaging of the larynx and acoustic and aerodynamic testing. The results of singers identified by their teachers and through self-report as having breathiness while singing were compared to singers identified as not having breathiness. The study by Schneider, et al. showed decreased vocal efficiency in normal speaking women as a result of insufficient glottal closure.⁴ Although similar studies have not been performed on singers, we hypothesized that the present study would demonstrate that glottic insufficiency contributes to breathiness in some singers.

Specific Aim 2: To identify quantitative measures (acoustic and aerodynamic) that best identify individuals with glottic insufficiency. We hypothesized that glottic

insufficiency would be reflected in select acoustic and aerodynamic measures, such as laryngeal airway resistance and subglottal pressure.

Significance of the study

While other studies have examined glottal closure for speech and singing or the significance of breath management in support, there has not been a study to determine if there is a correlation between glottic insufficiency and breathiness in singing.

Additionally, the present study includes a more holistic evaluation protocol in which the perspective of the voice teacher is combined with what is being discovered clinically.

Vocal pedagogy may benefit from increased awareness of current knowledge within voice science to identify the physiology contributing to vocal technique problems. A better understanding of vocal function for singing, specifically as breathiness relates to glottal configuration, may help voice teachers and students. Subsequently, voice students and singing teachers may benefit from increased involvement of a speech-language pathologist in the development of the singing voice.

Figure 2.1 *Normal closure*

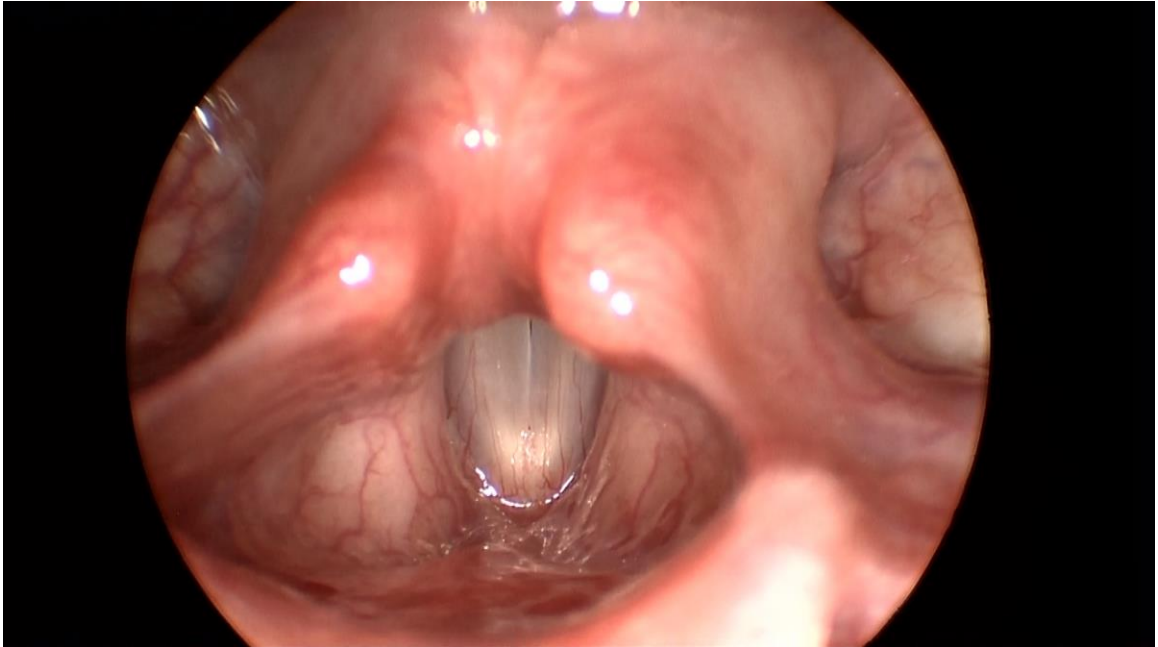


Figure 2.2 *Posterior gap*



Figure 2.3 *Anterior gap*



Figure 2.4 *Anterior and posterior gap*



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C H A P T E R 3 : METHODOLOGY

In Chapter 3 the methodologies will be discussed with details on study population, study design and statistical analysis. The purpose of this study was to examine the glottal function of singers to determine if there is a link between perceived breathiness in singing as observed by teacher and student in the voice studio, and glottic inefficiency as shown by visual imaging and other acoustic and aerodynamic tests performed in a clinical setup.

Study Population

A total of 36 participants were recruited for the study and divided into two initial groups: those with glottic insufficiency and those without. Subjects in this study were students between the ages of 20 and 45 years (mean: 26 years, standard deviation: 5.59 years) who were currently studying voice with a faculty member or doctoral teaching assistant at the University of Kentucky. The students were either junior or senior undergraduate or graduate students with a minimum of 4 semesters of private voice study. Subjects who had a history of any surface vocal fold pathology, or any neurological deficits were excluded from the study. Subjects who were found to have a vocal fold lesion were not included as part of the final analysis, but their data was stored to determine whether they were identified as having breathiness.

Subjects were recruited from the Voice Department of the School of Music at the University of Kentucky. Students taking voice lessons at the University of Kentucky were recruited by verbal announcements made by the Principal Investigator in weekly

studio class meetings. Participants were blinded to the true purpose of the study at the time of recruitment.

Study Design

The present study was a cohort study with a double-blind study assessment protocol. Subjects were divided into four groups for comparison and neither subjects nor assessors knew the true purpose of the study. In addition, the voice teacher for each student completed a survey and they were also blinded to the purpose of the study.

Subject Assessment

Subjects in all groups underwent an assessment of their voice and communication characteristics including a voice self-assessment, auditory-perceptual assessment, visual imaging of the laryngeal structure and a series of acoustic and aerodynamic measurements. The measures in each of these domains are detailed below in Table 3.1.

For the voice self-assessment, subjects completed the Singing Voice Handicap Index (SVHI). (Appendix C) The subjects were asked to complete the entire form, though only certain questions pertained to the purpose of the study. In the final analysis, the answers to nine specific questions dealing with breathiness and breath management were compared.

Visual imaging of the appearance and movements of laryngeal structures was accomplished using a rigid endoscope with a stroboscope attached, and a digital camera. Laryngeal videostroboscopy was performed using the Kay Elemetrics Rhino-Laryngeal Stroboscope – (Model RLS 9100 B, Halogen lamp: 150 watts, Xenon lamp: 120 watts, frequency range: 60 Hz – 1000 Hz, laryngeal microphone), a Kay Elemetrics 70 degree

rigid scope (Model 9106, total length: 252 mm) and a C-mount camera (Panasonic 3CCHD).

Prior to the exam, participants were trained by the Research Personnel in the proper production of the vowel /i/. The endoscope was placed in the subject's mouth and a recording was made of the larynx as he/she produced three different pitches (low, modal, high) on the vowel /i/. The subjects were then asked to perform a pitch glide from low to high on the vowel /i/ at a slow enough rate to accommodate the tracking capability of the equipment. Glottal configuration judgments were made at modal pitch only. Glottal configuration was then rated on a binary scale, where complete glottic closure will be rated as '0' and glottic insufficiency will be rated as '1'. Abnormal glottic closures were further characterized as having either a larger than normal posterior gap, anterior gap, irregular closure, bowing, phase asymmetry or other. (Appendix A) (Figure 3.1)

Two auditory-perceptual measures were taken for this study. The quality of the speaking voice during conversational speech was rated using the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V). (Appendix D) In addition, the voice teachers of students participating in the study were asked in a survey to rate elements of vocal technique in order of importance as it applies to each student. (Appendix E) The six criteria were articulation, *appoggio*, posture, intonation, breathiness in tone and resonance. If breathiness was listed in the top three, the subject was considered to have a perceived breath management issue. Issues related to *appoggio* were also noted for discussion.

Aerodynamic and acoustic measures were obtained while subjects made pre-determined sounds on an engaged voice (without vibrato) into a microphone and an airflow mask. Researchers then measured the air pressure and the airflow used during voice production. These tasks are described in detail below. Multiple attempts of voice samples and airflow measures were taken to ensure consistency.

The acoustic measurements taken for this study were fundamental frequency (F_0); the perturbation measures jitter and shimmer; maximum phonation time (MPT); and the noise-to-harmonics ratio (NHR). For acoustic assessment, the Computerized Speech Lab Model 4500 by

KayPentax was used with a hand-held microphone (mouth-to-microphone distance = 3 inches) [System Requirements: Analog Inputs: 4 channels: two XLR and two phono-type, 5mV to 10.5V peak-to-peak, adjustable gain range >38dB, 24-bit A/D, Sampling Rates: 8,000-200,000Hz, THD+N: <-90dB F.S. Frequency Response (AC coupled): 20-22kHz +.05dB at 44.1kHz. Digital Interface: AES/EBU or S/P DIF format, transformer-coupled. Software Interface: ASIO and MME. Computer Interface: PCI (version 2.2-compliant), PCI card; 5.0" H x 7.4" W x 0.75" D (half-sized PCI card). Analog Output: 4 channels, line and speaker, headphone output, channels 1 & 2 provide line & speaker outputs. Physical: 4" W x 8.25" H x 12.5" D, 4 lbs. 12 oz., 45 watts, speaker, and microphone (Shure SM-48 or equivalent, XLR-type)].³⁰

Fundamental frequency jitter, shimmer and noise-to-harmonics ratio were taken by having the subject sustain the vowel /a/ into a microphone held at a distance of 6 inches from the mouth. Participants were trained to produce a straight tone without

vibrato for these measures. Maximum phonation time was measured in seconds while the subject stood. The subject was asked to sustained the vowel /a/ at a comfortable pitch for as long as possible. (Figure 3.2)

The aerodynamics measures taken were vital capacity, mean airflow rate, subglottal pressure (P_{sub}), laryngeal airway resistance (LAR), and phonation threshold pressure (PTP). (See Appendix A: Checklist for Research Personnel) These measures help to interpret the valving activity of the larynx, including configuration. Airflow measures were taken using an airflow mask and a pneumotachograph, which uses the principle of differential pressure across a known resistance to estimate airflow rate. The Phonatory Aerodynamic system Model 6600 by KayPentax was used for the aerodynamic measurements (300 ml pneumotachograph - System requirements same as CSL model 4500).³¹

The vital capacity measure was taken by having the subject blow forcefully into the airflow mask until they were out of air. Laryngeal airway resistance and mean airflow rate were measured by having the subject place the airflow mask on their face with a tube placed intraorally, while saying /pa-pa-pa-pa-pa/. To measure phonation threshold pressure the subject was asked to speak the syllable /pi/ into an airflow mask starting from no voice, then increasing vocal intensity gradually to measure the point of onset of phonation. The subglottal pressure at the point of initiation of phonation is then marked and measured. (Figure 3.3)

Statistical Design

Based on the results of the teacher survey, subjects were further divided into four groups for statistical analysis: (1) Identified glottic insufficiency without perceived breathiness; (2) Adequate glottic sufficiency with perceived breathiness; (3) Identified glottic insufficiency with perceived breathiness; (4) Adequate glottic sufficiency without perceived breathiness. A fifth group consisted of subjects who were found to have vocal fold pathology on the initial assessment. Statistical analysis was then performed using SPSS v.21. A one-way ANOVA was performed to compare SVHI scores, CAPE-V, acoustic and aerodynamic parameters, stroboscopy and teacher survey results across the four groups under study. Additionally, multiple group-wise comparisons were also performed using an independent sample t-test.

Table 3.1 Domains and measures used in assessment

Assessment Domain	Measure
Self-assessment	Singing Voice Handicap Index (SVHI): Rated on a scale of 0-4
Auditory perceptual	Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V): Breathiness rated on a scale 0-100
Acoustic	Fundamental frequency (F0) (Hz) Jitter (%) Shimmer (dB) Noise-to-harmonics ratio (NHR) (dB)
Aerodynamic	Maximum phonation time (sec) Vital capacity (L) Mean airflow rate (L/sec) Subglottal pressure (Psub) (cm H ₂ O) Laryngeal airway resistance (LAR) (cm H ₂ O) Phonation threshold pressure (PTP) (cm H ₂ O)
Visualization	Presence or absence of glottic insufficiency (0 or 1)

Figure 3.1 *Videostroboscopy*



Figure 3.2 *Setting for acoustic assessment*

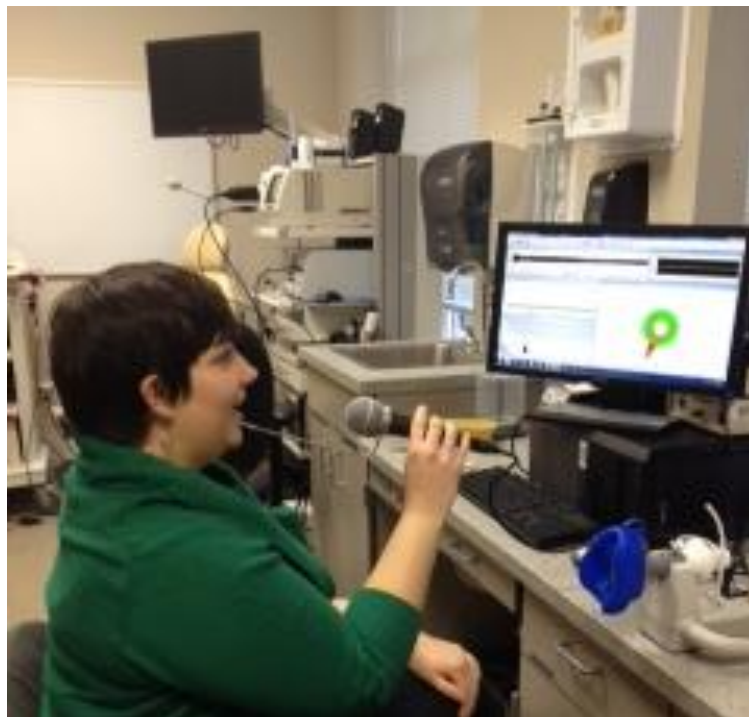


Figure 3.3 *Setting for aerodynamic assessment*



*All images used by permission of the University of Kentucky Voice and Swallow Clinic

C H A P T E R 4 : RESULTS

This chapter will present the readers with the results of the voice-assessment parameters and teacher surveys and the correlations within the data collected and analyzed using methods described in Chapter 3.

Participant Demographics

The data of 26 subjects was used for the final analysis, ranging in age from 20 to 45 years (mean age: 26 years, standard deviation: 6; Table 4.1). Twelve male (mean age: 25 years, range: 20 – 33 years) and fourteen female (mean age: 27 years, range: 21-45 years) subjects participated in the study. The distribution of voice types is listed in Table 4.2.

The subjects were divided into two initial groups: those with glottic insufficiency and those without. Based on the presence or absence of glottic insufficiency, subjects were further divided into four groups. These groups are specified in Table 4.3. An additional group consisted of the three subjects excluded from the study due to the presence of a surface pathology discovered at the time of data collection. Group 1, subjects with glottal insufficiency and no perceived breathiness, had 9 subjects all female with a mean age of 29 years (standard deviation: 7.84). Group 2, consisting of 1 female and 2 male subjects, were subjects with adequate glottal sufficiency and perceived breathiness. The mean age of the subjects was 23 years (standard deviation: 3.46). There were five subjects in Group 3, which consisted of subjects with glottal insufficiency and perceived breathiness. In Group 3, four subjects were female and one was male. The mean age was 22 years (standard deviation: 2.38). Finally, Group 4 had 9 subjects, all of whom were male. The subjects in this group had adequate glottal sufficiency and no

perceived breathiness. The mean age of subjects in this group was 27 years (standard deviation: 4.68).

An interesting gender distinction occurred when the subjects were divided into the four groups. All subjects with glottic insufficiency, but no perceived breathiness (Group 1) were female, while all subjects with adequate glottic sufficiency, and no perceived breathiness (Group 4) were male. The gender distribution in the four groups can be seen in Table 4.4.

Voice Parameters

As discussed, subjects underwent a holistic voice evaluation that included the five domains of voice assessment. The results of the voice assessment are discussed under each parameter. Audio-perceptual ratings (CAPE-V), acoustic (fundamental frequency, jitter, shimmer, maximum phonation time, noise-to-harmonics ratio) and aerodynamic (vital capacity, mean airflow rate, subglottal pressure, laryngeal airway resistance, phonation threshold pressure) measures, and visual imaging (videostroboscopy) were executed by the same licensed speech-language pathologist for all participants. Statistical analyses were performed to compare SVHI scores, CAPE-V scores, acoustic and aerodynamic parameters, stroboscopy ratings and teacher survey results across the four groups under study and between groups as well. Further correlations were determined between the voice parameters under assessment.

Stroboscopic Data

Visual imaging of the vocal folds showed glottic insufficiency in 14 of the subjects (Mean: .538; Standard deviation: .4707). Glottic configuration for all abnormal

stroboscopic results were further characterized as being posterior gap, anterior gap, irregular closure, bowing, phase asymmetry or other. These ratings were then compared to the results of the Voice Teacher Surveys.

Self-assessment and Audio-perceptual Data

Voice teachers were given a survey in which they were asked to rate six parameters of vocal technique in order of importance for each student (Appendix E). Subjects were rated '1' if breathiness was listed in the top three and '0' if it was not. Eight of 26 subjects, or 30% were rated '1.' (Mean: 0.308; Standard deviation: 0.4707) Five of the subjects identified in the teacher surveys as having breathiness in the voice also had glottic insufficiency. A comparison of stroboscopic results and teacher survey identification of breathiness can be seen in Table 4.5.

The scores for specific SVHI and CAPE-V parameters were compared to the teacher surveys in order to evaluate perception of breathiness. The five subjects identified by their teachers as having breathiness in the voice also presented with insufficient glottic closure (Group 3). However, only one of these subjects self-identified as struggling with breathiness in the results of the SVHI.

Nine of the 40 questions on the SVHI addressed issues of breath and were subsequently used for analysis. (Table 4.6) Specifically, statement F19 on the SVHI is "I have trouble controlling the breathiness in my voice." This statement was rated on a scale of 0-5, with 0 being "Never" and 5 being "Always." The mean rating for this answer was .538, with a standard deviation of .8115. While the scores for this question were low across subjects, there was a positive correlation between scores for F19 and the teacher-

identified breathiness in a subject. There is also a positive correlation between F19 and incomplete glottic closure, though it is not statistically significant. The results of the CAPE-V were normal for all but three subjects, two male and one female. The mean score for breathiness was 4, with a standard deviation of 5.2991.

Acoustic and Aerodynamic Data

The acoustic measures fundamental frequency, jitter, shimmer, noise-to-harmonics ratio, maximum phonation time, and the aerodynamic measures vital capacity, mean airflow rate, subglottal pressure, laryngeal airway resistance and phonation threshold pressure were collected for each subject and compared both within and across groups. In general, the acoustic measures were within normal limits. However, certain aerodynamic measures stood out, specifically laryngeal airway resistance. Means and standard deviations for the aerodynamic measures can be seen in Table 4.7.

For Group 1, the mean values for laryngeal airway resistance (47.9 cm H₂O) was slightly above normal measures, while maximum phonation time (14.382 sec) was low. Of the acoustic and aerodynamic measures for Group 2, laryngeal airway resistance was well above normal measures (132.28 cm H₂O) and mean airflow rate was below normal limits (.063 L/sec). For Group 3, the mean laryngeal airway resistance, 52.9 cm H₂O, was somewhat above normal limits. Laryngeal airway resistance and subglottal pressure were both above normal limits for Group 4. Laryngeal airway resistance was 57.83 cm H₂O and subglottal pressure was 7.3 cm H₂O.

Statistical Analysis

Comparisons were performed across the four groups under study using a one-way ANOVA. Additionally, independent sample t-tests were performed for multiple comparisons. Pearson's correlations were also performed between parameters of each group under study. The results of these analyses are described below and can be seen in Tables 4.8, 4.9, and 4.10.

The one-way ANOVA was performed across the four subject groups. The results showed that maximum phonation time and laryngeal airway resistance were significantly different across the four groups. (Table 4.8) However, when independent sample (t-test) comparisons were performed between groups, statistically significant differences were seen in jitter, shimmer, noise-to-harmonics ration and laryngeal airway resistance. (Table 4.9)

Pearson's correlations were performed across all subjects and variables under study. Positive correlations mean that as the values for Variable 1 increase, the values of Variable 2 increase as well. Negative correlations exist where the values of Variable 2 decreased as the values for Variable 1 increased. A correlation is considered significant when the significance level is less than 0.05.

The following correlations were found to be statistically significant. (Table 4.10) Jitter values increased as shimmer values increased. Increase in noise-to-harmonics ratio correlated to increase in vital capacity. Noise-to-harmonics was also shown to increase in correlation to normal glottal configuration. Maximum phonation time also increased in correlation to normal glottal configuration (complete closure). Mean airflow rate

increased with increased subglottal pressure. Mean airflow rate also increased in correlation to decreased laryngeal airway resistance. Increased laryngeal airway resistance was shown to correlate to normal glottal configuration, though the numbers were not statistically significant. Increased rating of breathiness was also shown to correlate to insufficient glottic closure, though not at a statistically significant rate.

In looking at the minimums and maximums for the acoustic and aerodynamic measures, laryngeal airway resistance and mean airflow rate stood out for two subjects. The subject with the lowest mean airflow rate (0.02 L/sec) had the highest laryngeal airway resistance (237.83 ml/sec) and the subject with the highest mean airflow rate (0.34 L/sec) had the lowest laryngeal airway resistance (16.95 ml/sec). Interestingly the former was a tenor ($F_0 = 124$ Hz) and the latter was a bass ($F_0 = 85$ Hz). The highest PTP (7.8 cm H₂O and P_{sub} (10.78 cm H₂O) came from the same subject, also a tenor ($F_0 = 119$ Hz).

Table 4.1 Age mean and standard deviation

	Age
Mean	26.115
Standard Deviation	6.0088
Minimum	20.0
Maximum	45.0

Table 4.2 Distribution of Subjects by Voice Type

Voice Type	Number of Subjects
Sopranos	13
Mezzo-soprano	1
Tenors	6
Baritones	4
Basses	2

Table 4.3 Subject Groups

Group	Criteria	Number of subjects	Percentage
1	Glottal insufficiency, no breathiness	9	34.6%
2	Glottal sufficiency, breathiness	3	11.5%
3	Glottal insufficiency, breathiness	5	19.2%
4	Glottal sufficiency, no breathiness	9	34.6%

Table 4.4 Gender distribution in groups

	Male	Female
Group 1	0	9
Group 2	2	1
Group 3	1	4
Group 4	9	0

Table 4.5 Strobe ratings and teacher surveys

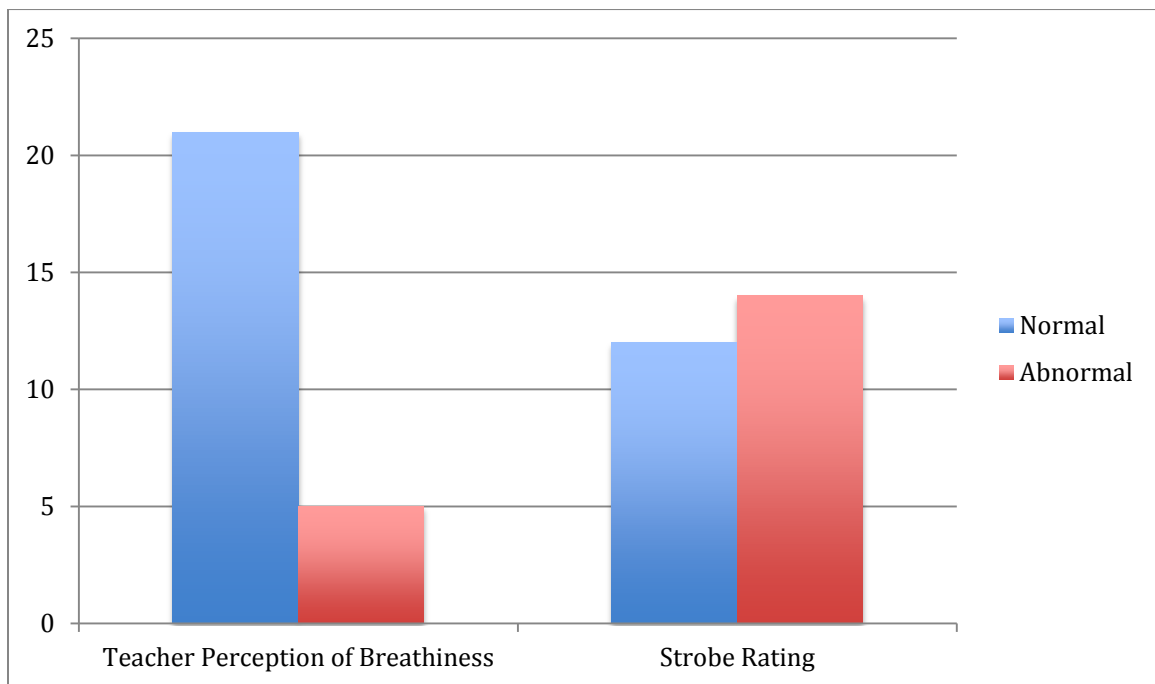


Table 4.6 SVHI means and standard deviation

	F1	P2	F6	P18	F19	P20	P21	P26	P29	Total
Mean	.962	1.115	.538	.731	.538	.269	.308	1.038	1.038	6.538
Standard Deviation	.8709	.7656	.7060	.7776	.8115	.6038	.6177	.8709	1.0385	4.7769
Minimum	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Maximum	3.0	3.0	2.0	3.0	3.0	2.0	2.0	3.0	3.0	21.0

Table 4.7 Aerodynamic means and standard deviations

	Vital Capacity (L)	Mean Airflow Rate (L/sec)	Subglottal Pressure (cm H₂O)	Laryngeal Airway Resistance (cm H₂O)	Phonation Threshold Pressure (cm H₂O)
Mean	4.1419	.1550	7.0746	62.0415	3.6381
Standard Deviation	1.18051	.08571	1.72516	48.54122	1.45469
Minimum	2.11	.02	3.88	16.95	1.16
Maximum	6.71	.34	10.78	237.83	7.18

Table 4.8 One-way ANOVA

Parameter	p-value
Maximum Phonation Time	0.02
Laryngeal airway resistance	0.05

Table 4.9 Pairwise Comparisons

Parameter	Groups compared	p-value
Jitter	1 and 2	0.034
	2 and 3	0.048
Shimmer	1 and 3	0.037
NHR	1 and 4	0.023
	3 and 4	0.022
LAR	1 and 2	0.028
	2 and 4	0.008

Table 4.10 Statistically significant correlations

Variable 1	Variable 2	P-values	Correlation
Jitter	Shimmer	0.002	Positive
NHR	Strobe	0.003	Negative
MPT	Strobe	0.007	Negative
Airflow rate	P _{sub}	0.03	Positive
Airflow rate	LAR	0.00	Negative

C H A P T E R 5 : DISCUSSION

To reiterate, the initial problem identified at the beginning of this paper is as follows: An issue that is perceived by voice students and voice teachers as being related to breath support may potentially be the result of air loss due to incomplete closure of the vocal folds during voice production. Since the larynx cannot easily be observed without the assistance of clinical instrumentation, issues at the glottal level may not be recognized as contributing to technical issues in the singing studio.

The present study tested two hypotheses. The first hypothesis suggested that glottic insufficiency contributes to breathiness in some singers. Although a positive correlation was noted between breathiness and glottic insufficiency, this correlation was not statistically significant. More students presented with glottic insufficiency than were identified as having breathiness. Therefore the results did not support the first hypothesis that there is a relationship between singers with perceived breathiness in the voice and the presence of glottic insufficiency.

The second hypothesis that certain acoustic and aerodynamic measures would stand out as identifying characteristics of glottic insufficiency was supported by the data. The acoustic and aerodynamic measures noise-to-harmonics ratio, maximum phonation time, airflow rate, subglottal pressure, and laryngeal airway resistance were most sensitive to glottic insufficiency. These results correspond to measures as reported in literature.^{7,17}

Murry, et al. found that airflow rate increased as glottal closure decreased.¹⁷ The results of the present study showed similar findings where a statistically significant

negative correlation was found between mean airflow rate and laryngeal airway resistance. Mean airflow rates were shown to increase as laryngeal airway resistance decreased. Laryngeal airway resistance is the ratio of subglottal pressure to mean airflow rate and is considered a valuable measure of glottic efficiency.⁷ This study further strengthens the use of laryngeal airway resistance and mean airflow rate as a reliable measure for glottic closure.

All subjects reported by their teachers as working on breathiness in their voice had incomplete glottal closure. Conversely, a large number of subjects (34% of total subjects) were shown through videostroboscopy to have glottic insufficiency, but were not reported as having breathiness. All subjects with incomplete glottic closure were reported to be working on *appoggio* in their lessons. This suggests that glottic insufficiency may contribute to inefficient breath management without presenting any audio-perceptual indication, however further study would need to be done. It is important to note that among voice teachers a certain amount of breathiness is considered normal in adolescent voices.^{2,32} Since the parameter breathiness was not defined in the Voice Teacher Survey, it is possible that teachers may not have reported it as a problem, even if it was present.

Discrepancies in interpretation of vocal technique and ambiguity of terminology can present a challenge. As mentioned above, some breathiness may be considered normal in an adolescent voice.^{2,32} The concept of “mutational chink” or the larger than normal posterior gap that is sometimes present in adolescent or changing voices has consequently become a common explanation for breathiness in the singing voice. However this concept may not be applicable to the mature singer, since a larger than

normal posterior glottic gap and concurrent breathiness may indicate weakness of the interarytenoid muscles in a developmentally mature voice.^{33,34}

Schneider, et al. found that incomplete glottal closure translated to the limited capacity to increase the intensity of the singing and speaking voice.⁴ They also hypothesized that a larger than normal posterior glottal chink is a potential risk factor for developing functional voice disorders as a result of compensatory hypertension or maladaptive behavior. However, they also suggested that glottic insufficiency only becomes problematic when singers begin to compensate. Studies by Sataloff, et al. and Lundy, et al. have shown a high incidence of abnormalities in otherwise asymptomatic professional voices.^{21,22} Their results also support the suggestion that the presence of glottic insufficiency may not translate into a significant vocal problem for a singer. The high incidence of subjects with glottic insufficiency and no perceived breathiness found in the present study may further support these observations.

The present study found lower maximum phonation times in subjects with glottic insufficiency. Studies by Sabol, et al. and Tay, et al. found improved maximum phonation time after vocal therapy, suggesting increased glottic efficiency.^{6,16} This may suggest that a student with glottic insufficiency may benefit from voice therapy to improve their vocal efficiency.

Limitations

There were several limitations and weaknesses in the present study. The sample size was small. Due to the small sample size there was an uneven distribution of subjects into the four primary groups. In many cases, correlations within the acoustic and

aerodynamic measures and glottic insufficiency indicated trending, but were not statistically significant.

An additional limitation was that subjects were not measured while singing. Subjects were asked to perform all tasks on an engaged voice, but with no vibrato. The position required for the endoscope is uncomfortable and awkward, so results may not truly represent a fully supported singing voice. The constraints of the present study did not, however, allow for the use of a flexible naso-endoscope. It would be interesting to conduct a future study using this instrument, which would allow researchers to observe glottic closure while subjects produced a fully supported singing voice. Conversely, one drawback to the use of the naso-endoscope is that there are no norms for rating the singing voice.

Students were not asked specifically about their own perception of breathing, breath support or breathiness. In the self-assessment surveys, very few subjects rated high scores on questions pertaining to breathiness even though some were identified by their teachers as working on breathiness. Also, in the survey completed by voice teachers, breathiness and *appoggio* were not defined.

Discussion for Singers and Voice Teachers

When the great voice teacher Manuel Garcia used an angled mirror to look at his own vocal folds, he ushered in the modern era of laryngology.¹ Curiosity about the vocal mechanism and function has led hundreds of singers and voice teachers to seek a better understanding of their instrument, as evidenced by the many resources existing in the vocal pedagogy text canon. Since the 19th century, instrumentation has improved,

allowing singers to see high-definition video images of their vocal folds during phonation. This has allowed scientists and singers to gain a deeper understanding of the function and physiology of the larynx.

Students may benefit as well from these technological advances with regular wellness screenings at a voice clinic to gain an increased awareness of the inner workings of their instrument. Unlike other musicians, who can see and touch their instruments and even build and repair them, singers carry their instruments within their body. Seeing high-definition video images of the vocal folds and understanding the importance of optimal vocal function for vocal efficiency and health gives voices students more tools for success as an artist.

The relationship between singers and the voice clinic should be like the relationship between athletes or professional ballerinas and sports medicine. Athletes and ballerinas are expected to perform at elite levels, so they are required to maintain a high level of physical fitness. They are regularly referred to doctors and physical therapists, which are often on the staff of the team or company, for routine check-ups and treatment of injuries. Singers are considered elite vocal athletes and must also maintain a high level of vocal health. Speech-language pathologists and ENTs can provide that much needed physiologic support.

The effect of vocal efficiency on the quality of the singing voice has not yet been quantified. Indeed, how improved vocal efficiency impacts the quality of the singing voice is a subjective discussion and beyond the scope of this paper. It may be safe, however, to suggest that students struggling with breathiness or breath management

issues in their singing may have incomplete glottic closure and could benefit from clinical voice therapy. It may also be proposed that continued collaboration between speech-language pathologists and voice teachers might result in the development of better vocal therapy exercises specifically for singers.

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APPENDICES:

- A. Checklist
- B. Informed Consent
- C. SVHI
- D. CAPE-V
- E. Voice Teacher Survey
- F. Glossary

Appendix A: Checklist for Research Personnel

E. Graham Study Checklist for Research Personnel

Please fill out and attach to SVHI and CAPE-V for each subject.

Subject #: _____

Informed consent: ☐

SVHI: ☐

CAPE-V: ☐

Acoustics:

F₀	
Jitter	
Shimmer	
NHR	

Aerodynamics:

MPT standing	
Vital capacity	
Mean airflow during voicing	
Subglottal pressure	
Laryngeal airway resistance	
Phonation threshold pressure	

Strobe: 0= normal / 1= Abnormal

If abnormal: (*select one*)

Posterior gap (<i>larger than normal</i>)	
Anterior gap	
Irregular closure	
Bowing	
Phase asymmetry	
Other	

If other, please identify: _____

Appendix B: Informed Consent

Consent to Participate in a Research Study

THE ROLE OF LARYNGEAL FUNCTION IN BREATH SUPPORT FOR SINGING

WHY ARE YOU BEING INVITED TO TAKE PART IN THIS RESEARCH?

You are being invited to take part in a research study that will examine the laryngeal function of voice students. You are being invited to take part in this research because you are studying voice at the University of Kentucky and have taken a minimum of 4 semesters of voice lessons with a professor of voice or a graduate teaching assistant. If you volunteer to take part in this study, you will be one of about 40 people to do so.

WHO IS DOING THE STUDY?

The persons in charge of this study are Ellen Graham, D.M.A candidate, and Joseph Stemple, Ph.D., CCC-SLP, both of University of Kentucky. There may be other people on the research team assisting at different times during the study.

WHAT IS THE PURPOSE OF THIS STUDY?

By doing this study, we hope to learn more about how laryngeal function influences breath support for the singing voice.

ARE THERE REASONS WHY YOU SHOULD NOT TAKE PART IN THIS STUDY?

You should not take part in this study if you are younger than 18 years or older than 64 years of age, or are a smoker. You should not currently have voice problems or any acute or chronic disease affecting the voice (e.g., sinusitis), history of a voice disorder, vocal pathology, laryngeal trauma or surgery.

You should not have had fewer than 4 semesters of private voice study at the college level with a voice professor or graduate teaching assistant. You must currently be studying voice.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

All research procedures will be conducted at the University of Kentucky Voice and Swallow Clinic, on the 3rd floor of the Kentucky Clinic. The voice assessment will take on average one hour. The total amount of time you will be asked to volunteer for this study is about one hour on one day.

WHAT WILL YOU BE ASKED TO DO?

At your arrival, we will assess your voice and communication characteristics including:

- *Voice self-assessment.* Singer's Voice Handicap Index (SVHI); a self-administered questionnaire that will be completed by each participant.
- *Visual imaging of the appearance and movements of vocal/laryngeal structures.* To accomplish this, a rigid endoscope attached to a digital camera and recorder will be placed in the subject's mouth and a recording will be made of the larynx as he/she produces three different pitches (low, modal, high) on the vowel /i/. Glottal configuration judgments will be made at modal pitch only. Glottal configuration will be rated on a binary scale, where complete glottic closure will be rated as '1' and glottic insufficiency will be rated as '0'.
- *Audio-visual recordings of your spontaneous speaking and reading and audio-recordings of your speech and voice production.* These measures will be obtained while you say pre-determined sounds and short sentences into a microphone and an airflow mask. Researchers will then measure the air pressure and the airflow out of your mouth that you use during voice production. Voice samples and airflow measures can take several attempts to ensure consistency.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

To the best of our knowledge, the things you will be doing have no more risk of harm than you would experience in everyday life. During the assessment, the scope will be placed in your mouth to view your vocal folds. This may be momentarily uncomfortable, due to gagging in some cases. If your vocal folds show any abnormality, you will be referred to an Ear, Nose and Throat physician in the Kentucky Clinic. There are no known risks associated with audio recording or collecting air coming out of your mouth during speech. There is always a chance that any medical treatment can harm you, and the investigational treatment in this study is no different. In addition to the risks listed above, you may experience a previously unknown risk or side effect.

WILL YOU BENEFIT FROM TAKING PART IN THIS STUDY?

There is no guarantee that you will get any benefit from taking part in this study. However, your willingness to participate may, in the future, help speech-language

pathologists, ear-nose-throat doctors specialized in voice disorders and voice teachers better understand vocal function in singers.

DO YOU HAVE TO TAKE PART IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering. As a student, if you decide not to take part in this study, your choice will have no effect on your academic status or grades. Data will not be collected in the classroom. All study records will be kept confidential.

IF YOU DON'T WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?

If you do not want to be in the study, there are no other choices except not to take part in the study.

WHAT WILL IT COST YOU TO PARTICIPATE?

There is no cost to you or your insurance company for you to participate in this study.

WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

You will not receive any rewards or payment for taking part in the study.

WHO WILL SEE THE INFORMATION THAT YOU GIVE?

We will keep private all research records that identify you to the extent allowed by law.

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

Your personal information will be accessible only to research personnel. We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. However, your teacher will be asked about your singing voice before we conduct the study and/or your teacher's opinions on your singing voice and technique will be sought during the study.

CAN YOUR TAKING PART IN THE STUDY END EARLY?

If you decide to take part in the study you still have the right to decide at any time that you no longer want to continue. You will not be treated differently if you decide to stop taking part in the study. Any identifiable research information resulting from your participation in this research study prior to the date that you formally withdraw your

consent may continue to be used and disclosed by the investigators for the purpose described in the previous section.

You will be withdrawn from this study if your voice assessment reveals a vocal pathology.

ARE YOU PARTICIPATING OR CAN YOU PARTICIPATE IN ANOTHER RESEARCH STUDY AT THE SAME TIME AS PARTICIPATING IN THIS ONE?

You may take part in this study if you are currently involved in another research study. It is important to let the investigator/your doctor know if you are in another research study. You should also discuss with the investigator before you agree to participate in another research study while you are enrolled in this study.

WHAT HAPPENS IF YOU GET HURT OR SICK DURING THE STUDY?

If you believe that you have gotten hurt or sick as a result of participation in this study contact Ellen Graham at evgr222@uky.edu and Dr. Joseph Stemple at jcstem2@uky.edu. In case an abnormality of your voice is found during the assessment you will be referred to the UK Voice and Swallow Clinic. Should you choose to proceed with treatment, you and/or your insurance company will be responsible for the costs of all care and treatment.

It is important for you to understand that the University of Kentucky does not have funds set aside to pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. Also, the University of Kentucky will not pay for any wages you may lose if you are harmed by this study.

The medical costs related to your care and treatment because of research related harm will be your responsibility.

You do not give up your legal rights by signing this form.

WHAT IF NEW INFORMATION IS LEARNED DURING THE STUDY THAT MIGHT AFFECT YOUR DECISION TO PARTICIPATE?

If the researcher learns of new information in regards to this study, and it might change your willingness to stay in this study, the information will be provided to you. You may be asked to sign a new informed consent form if the information is provided to you after you have joined the study.

WHAT ELSE DO YOU NEED TO KNOW?

There is a possibility that the data collected from you may be shared with other investigators in the future. If that is the case the data will not contain information that can identify you unless you give your consent or the UK Institutional Review Board (IRB) approves the research. The IRB is a committee that reviews ethical issues, according to federal, state and local regulations on research with human subjects, to make sure the study complies with these before approval of a research study is issued.

WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS, CONCERNS, OR COMPLAINTS?

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions, suggestions, concerns, or complaints about the study, you can contact the investigator, Ellen Graham at 513-461-3596. If you have any questions about your rights as a volunteer in this research, contact the staff in the Office of Research Integrity at the University of Kentucky at 859-257-9428 or toll free at 1-866-400-9428. We will give you a signed copy of this consent form to take with you.

Signature of person agreeing to take part in the study

Date

Printed name of person agreeing to take part in the study

Name of [authorized] person obtaining informed consent

Date

Signature of Investigator

Appendix C: SVHI

NAME _____

Date _____

SingingVoice Handicap Index (VHI)

Instructions: These are statements that many people have used to describe their singing and the effects of their singing on their lives. Circle the response that indicates how frequently you have had the same experience in the last month.

		Never	Almost Never	Sometimes	Almost Always	Always
F1	It takes a lot of effort to sing.	0	1	2	3	4
P2	My voice cracks and breaks.	0	1	2	3	4
F3	I am frustrated by my singing.	0	1	2	3	4
P4	People ask "What is wrong with your voice?" when I sing.	0	1	2	3	4
F5	My ability to sing varies day to day.	0	1	2	3	4
F6	My voice "gives out" on me while I am singing.	0	1	2	3	4
E7	My singing voice upsets me.	0	1	2	3	4
F8	My singing problems make me not want to sing/perform.	0	1	2	3	4
E9	I am embarrassed by my singing.	0	1	2	3	4
P10	I am unable to use my "high voice."	0	1	2	3	4
F11	I get nervous before I sing because of my singing problems.	0	1	2	3	4
F12	My speaking voice is not normal.	0	1	2	3	4
P13	My throat is dry when I sing.	0	1	2	3	4
P14	I've had to eliminate certain songs from my singing/performances.	0	1	2	3	4
E15	I have no confidence in my singing voice.	0	1	2	3	4
F16	My singing voice is never normal.	0	1	2	3	4
P17	I have trouble making my voice do what I want it to.	0	1	2	3	4
P18	I have to "push it" to produce my voice when singing.	0	1	2	3	4
F19	I have trouble controlling the breathiness in my voice.	0	1	2	3	4
P20	I have trouble controlling the raspiness in my voice.	0	1	2	3	4
P21	I have trouble singing loudly.	0	1	2	3	4
F22	I have difficulty staying on pitch when I sing.	0	1	2	3	4
E23	I feel anxious about my singing.	0	1	2	3	4
E24	My singing sounds forced.	0	1	2	3	4

		Never	Almost Never	Sometimes	Almost Always	Always
E25	My speaking voice is hoarse after I sing.	0	1	2	3	4
P26	My voice quality is inconsistent.	0	1	2	3	4
E27	My singing voice makes it difficult for the audience to hear me.	0	1	2	3	4
E28	My singing makes me feel handicapped.	0	1	2	3	4
E29	My singing voice tires easily.	0	1	2	3	4
E30	I feel pain, tickling, or choking when I sing.	0	1	2	3	4
E31	I am unsure of what will come out when I sing.	0	1	2	3	4
E32	I feel something is missing in my life because of my inability to sing.	0	1	2	3	4
E33	I am worried my singing problems will cause me to lose money.	0	1	2	3	4
E34	I feel left out of the music scene because of my voice.	0	1	2	3	4
E35	My singing makes me feel incompetent.	0	1	2	3	4
E36	I have to cancel performances, singing engagements, rehearsals, or practices because of my singing.	0	1	2	3	4

***Please circle the word that matches how serious you feel your voice problem is:

No Problem Mild Problem Moderate Problem Severe Problem

***Please circle the word that matches how you feel your voice is today:

No Problem Mild Problem Moderate Problem Severe Problem

On a scale of 1-10, with 1 being least talkative and 10 being most talkative, how would you rate yourself?

On a scale of 1-10, with 1 being softest and 10 being loudest, how would you rate yourself?

For Clinician Use Only:

P Scale _____ F Scale _____ E Scale _____ Total _____

Cohen, S.M., Jacobson, B.H., Garrett, C.G., Noordzij, J.P., Stewart, M.G., Attia, A., Ossoff, R.H., Cleveland, T.F. (2007) Creation and validation of the Singing Voice Handicap Index. *Annals of Otolaryngology & Laryngology*, 116(6), 402-406

Appendix D: CAPE-V

Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V)

Name: _____

Date: _____

The following parameters of voice quality will be rated upon completion of the following tasks:

1. Sustained vowels, /a/ and /i/ for 3-5 seconds duration each.

2. Sentence production:

a. The blue spot is on the key again.

b. How hard did he hit him?

c. We were away a year ago.

d. We eat eggs every Easter.

e. My mama makes lemon muffins.

f. Peter will keep at the peak.

3. Spontaneous speech in response to: "Tell me about your voice problem." or "Tell me how your voice is functioning."

Legend: C = Consistent I = Intermittent
MI = Mildly Deviant
MO = Moderately Deviant
SE = Severely Deviant

SCORE

Overall Severity _____ C I /100
MI MO SE

Roughness _____ C I /100
MI MO SE

Breathiness _____ C I /100
MI MO SE

Strain _____ C I /100
MI MO SE

Pitch (Indicate the nature of the abnormality): _____ C I /100
MI MO SE

Loudness (Indicate the nature of the abnormality): _____ C I /100
MI MO SE

_____ C I /100
MI MO SE

_____ C I /100
MI MO SE

COMMENTS ABOUT RESONANCE: NORMAL OTHER (Provide description): _____

ADDITIONAL FEATURES (for example, diplophonia, fry, falsetto, asthenia, aphonia, pitch instability, tremor, wet/gurgly, or other relevant terms): _____

Clinician: _____

Appendix E: Voice Teacher Survey

Voice Teacher Survey for _____.

Rate the following aspects of technique in order of greatest priority for this student in his/her voice lesson. List them in order 1 to 6, with 1 being the most important technique issue and 6 being the least important technique issue.

Intonation
Breathiness in tone
Posture
Appoggio
Articulation
Resonance

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____

Name: _____

Signature: _____

Appendix F: Glossary of Clinical Measures

- *Fundamental frequency (F_0)*: Acoustic correlate of pitch; represents the number of vibrations of the vocal folds per second. It is measured in Hertz (Hz).¹² The normal range of fundamental frequency is 100 to 150 Hz for males and 180 to 250Hz for females.
- *Jitter*: Measure of pitch perturbation and is the cycle-to-cycle variation in frequency. It may be measured in percentage (%) of mean cycle-to-cycle perturbation in frequency to the mean overall frequency of the voice signal.^{12,13} Normative data for jitter is less than 1.00%.¹⁴
- *Laryngeal airway resistance (LAR)*: Ratio of subglottal pressure to mean airflow rate; a valuable measure of glottal efficiency.⁷ In normal voices LAR is 30-45 cm H₂O (L/sec).¹³
- *Maximum phonation time (MPT)*: Maximum duration that a vowel can be sustained while using maximum airflow volume.¹ This measure varies with age, sex, size and health, however a range of 15-30 seconds has been observed in normal voiced adult males and females.¹²
- *Mean airflow rate*: Also called mean airflow during voicing, is the total volume of air used during phonation for the duration of phonation. It is defined in liters per second (L/sec).⁷ Normal measures for mean airflow rate are 80-200 ml/sec.
- *Noise-to-harmonics ratio (NHR)*: Measure of the acoustic noise energy in the voice signal. NHR is considered normal when it is less than .19.^{1,13,14} A high level of noise is indicative of aperiodic vocal fold vibration and breathiness.
- *Phonation threshold pressure (PTP)*: Minimum subglottal pressure needed to initiate vocal fold vibration, measured at the quietest possible initiation of voicing. Normal measures for phonation threshold pressure are 3-5 cm H₂O.⁷
- *Shimmer*: Unit of measurement of the small cycle-to-cycle changes of the amplitude of the vocal fold signal. It is measured in decibels (dB).¹³ Normative data for shimmer is less than .35 dB.
- *Subglottal pressure (P_{sub})*: Measurement of air pressure beneath the vocal folds necessary to overcome the resistance of the approximated folds to initiate and maintain phonation.¹ Normal measures for subglottal pressure (P_{sub}) are 5-8 cm H₂O. Intraoral pressure measures are used to infer subglottal pressure, since determining actual subglottal pressure would require a needle puncture into the trachea. During the production of the letter “p,” the glottis is open and the lips are closed. In this brief period of time the pressure within the mouth should equal that at the level below the glottis, since pressure tends to equalize within a closed space. To record the intraoral pressure an oral tube is placed between the closed lips and connected to a pressure transducer.
- *Vital capacity*: Maximum amount of air a person can expel from their lungs after a maximum inhalation, measured in liters.¹ This measure varies with age, sex, size and health.

Vita

- Place of birth: Cincinnati, OH
- Educational institutions attended and degrees already awarded: Carnegie Mellon University, BFA 2003; Miami University, MM 2007
- Professional positions held: Adjunct Professor of Voice at Transylvania University
- Typed name of student on final copy: Ellen Graham